The Steam System Assessment Tool (SSAT): Estimating Steam System Energy, Cost, and Emission Savings

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The U. S. Department of Energy's (DOE) BestPractices Steam program is developing software tools to assist industrial energy users to improve the efficiency of their steam systems. Many steam systems offer energy savings opportunities that can amount to 10% to 20% of fuel costs.

In December 2002, BestPractices Steam released a major new software tool—the Steam System Assessment Tool (SSAT). SSAT is designed to allow steam analysts to develop approximate models of real steam systems. Using these models, SSAT can be applied to quantify the magnitude—energy, cost, and emission savings—of key potential steam improvement opportunities. SSAT is a reliable screening tool that contains the key features of typical steam systems. The tool is designed for use by engineers who operate or improve the operations of steam systems.

SSAT was developed for DOE, under contract with the Oak Ridge National Laboratory, by Linnhoff March and Spirax Sarco, Inc.

This paper discusses the most important characteristics of SSAT, and describes the process used to develop the initial version of the tool that was released in December 2002. Major benefits that can result from using SSAT are then presented. Finally, future activities related to training on the use of SSAT and future modifications to the software are discussed.

Evaluating the "What-If" Steam System Improvement Scenarios

An accurate way to analyze potential steam system savings is to build a model of a steam system and to then use that model to evaluate "what-if" steam system improvement scenarios. SSAT is designed to model steam systems in this way. SSAT uses a graphical model of a generic steam system for up to three steam pressure headers: high, medium, and low. These types of major steam system equipment can be simulated using SSAT:

- Boilers
- Backpressure turbines
- Condensing turbines
- Deaerators
- Steam traps, leaks, insulation losses
- Letdowns
- Flash vessels
- Feedwater heat exchangers.

SSAT users can enter data for their plant conditions. This includes fuel type and cost, electricity and water costs, initial boiler efficiency, header pressures, turbine efficiencies, etc. Then, they can then evaluate "what-if" scenarios for the following types of key improvement opportunities:

- Using an alternative boiler fuel
- Improving boiler efficiency
- Reducing boiler blowdown rate
- Changing steam generation conditions
- Installing a blowdown flash system to produce low-pressure steam
- Installing new backpressure turbine(s)
- Installing a new condensing turbine
- Installing new heat recovery exchangers to preheat feedwater
- Increasing condensate recovery
- Reducing steam trap losses and losses from steam leaks
- Reducing pipe work insulation heat losses.

SSAT software runs as an add-in within Microsoft® Excel spreadsheet software.

Three initial software templates are provided with the software for "1-header," "2-header," and "3-header" pressure template models. These models are Excel files (*.xls) that require the SSAT software to be loaded to function properly.

Each of the SSAT model templates includes six worksheets: Input, Model, Projects Input, Projects Model, Results, and User Calculations. The major functions of these six worksheets are described below.

- The **Input** worksheet allows the SSAT user to enter data specific to the operation of a given steam system. Upon installation, the SSAT template files provided already contain default data, but this data can be overwritten for the steam system being modeled. Appendix 1 illustrates a portion of the Input sheet for the 3-header template model.
- The **Model** worksheet shows a schematic of the steam system being modeled that is based on the data entered in the Input worksheet. Appendix 2 shows the Model schematic for the 3-header template model.
- The **Projects Input** worksheet allows the SSAT user to select one or more pre-defined steam improvement projects to evaluate. Appendix 3 illustrates a portion of the Projects Input worksheet for the 3-header template. The SSAT user, for example, could evaluate the potential for implementing "Project 2—Change Boiler Efficiency" by changing the existing boiler efficiency to a new value and determining how this changes energy, cost, and emissions values for the steam system being modeled.
- The **Projects Model** worksheet is similar to the Model worksheet discussed above except that the schematic now shows the updated steam system conditions for the projects specified in the Projects Input worksheet.
- The **Results** worksheet shows the key energy, cost, and emissions results for the initial system conditions, specified in the Input worksheet, and the system conditions resulting from implementing steam system opportunities, specified in the Projects Input worksheet. As shown in Appendix 4, the results are presented in tabular form, allowing the SSAT user to quickly assess the impact of any proposed changes to their steam system.
- Finally, SSAT includes a **User Calculations** worksheet, with which the software user can perform any supplemental calculations that might be needed for using SSAT.

Developing the Initial Version

The SSAT Software Development Team consisted of the authors of this paper. The effort to develop the SSAT software was initiated in March 2002. At that time, a meeting was held to discuss the following topics:

- Overall purpose for the software
- Software inputs and outputs
- Details of the software structure
- Software usability to ensuring that SSAT would be made as simple to use as possible
- How software verification calculations would be performed
- How technical review of the beta version of the software will be conducted
- Development of an outline for the software users guide.

Based on the March 2002 meeting to set the initial SSAT software requirements, the first beta version was completed in early July 2002. At that time, a number of steam system experts were asked to perform a technical review of the software. The experts and organizations that performed the SSAT software technical review are listed in the Acknowledgements section of this paper. The technical reviewers were given 2 months to provide their technical review comments on the software.

To verify the accuracy of the SSAT modeling approach, Dr. Greg Harrell performed SSAT calculations for sample problems that are contained in the *Steam System Survey Guide* (1). Agreement between the guide's results and the SSAT results was excellent.

The SSAT Software Development Team responded to the comments from the technical reviewers. At the same time that final software modifications were being made, the SSAT Users Guide (which is available as a PDF file and as a "Help" file within the software) was completed.

The SSAT software was initially released through the DOE BestPractices Web site at *www.eere.energy.gov/industry/bestpractices* in December 2002. A stand-alone CD version of the software was released in January 2003. The SSAT is also included on the Decision Tools for Industry CD, which contains all of the DOE BestPractices software tools.

SSAT Benefits

In designing SSAT, efforts by the Software Development Team focused on ensuring that it would be a useful tool for identifying opportunities to improve steam systems. The key benefits of using the SSAT are described below:

- The SSAT can be used to model the major improvement opportunities that are typically possible in steam systems. In addition, SSAT can model more than one opportunity at a time, so that the user can see how multiple opportunities affect the results.
- The SSAT was designed based on the "80/20" principle. It was developed to be powerful enough to model major steam improvement opportunities, but was kept simple by not attempting to model all potential steam improvements.
- The SSAT data input interface is simple to use. For many real steam systems, it is expected that a system model can be set up in a few hours or less.
- The SSAT has models for estimating both on-site and off-site emissions. The user can see how reducing fuel use affects on-site emissions of CO_2, SO_X, and NO_X. Including both on-site and off-site emissions can be very important for modeling the environmental effects of generating on-site power using backpressure turbine generators.
- In addition to being a steam system analysis tool, the SSAT can also be used as a training tool. The Model and Projects Model graphical worksheets illustrate how various modeling changes influence the steam system being modeled SSAT is a true system-modeling tool.

More to Come!

As of July 2003, there are more than 1,300 registered users of SSAT software.

The BestPractices Steam program presents 1-day steam End User training, where SSAT examples are presented. In addition, a BestPractices Steam Qualified Specialist training program has been developed to qualify users who want to become experts in the use of SSAT software and other BestPractices Steam tools.

It is expected that there will be future versions of SSAT released, based on feedback from users of the software. Updates will include corrections to any modeling errors discovered, and will perhaps include additional or enhanced modeling based on user feedback.

Summary and Conclusions

SSAT is a major addition to the overall "toolbox" that the DOE BestPractices Steam program has developed for the steam user community. Use of SSAT is expected to greatly enhance the awareness of the many opportunities that are available for improving the efficiency and productivity of steam systems.

References

1. Dr. Greg Harrell, *Steam Survey Guide,* ORNL/TM-2001/263, May 2002.

Acknowledgements

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- Sunoco
- University of Tennessee/Knoxville
- Washington State University

Appendix 1. SSAT "Input " Worksheet, 3-Header Template (Full Sheet Not Shown)

Steam System Assessment Tool

3 Header Model

Data Entry Form for Current System

The data entry form is split into two sections. *"Quick Start"* enables you to enter a minimum amount of information about your site and to start modeling your system right away. *"Site Detail"* allows you to provide more detailed information about your site to improve the accuracy of the model.

Yellow shaded cells require user input.

Where different options can be chosen by the user, the required supplementary data input cells are shaded green and are indicated by *red arrows* .

Quick Start

Enter Case Description	SSAT Default 3 Header Model

General Site Data	**Input Data**	**Notes/Warnings**
Site Power Import (+ for import, - for export)	5000 kW	Power import + site generated power = site electrical demand
Site Power Cost	0.0700 $/kWh	Typical 2002 value: $0.07/kWh
Operating hours per year	8000 hrs	
Site Make-Up Water Cost	0.0025 $/gallon	Typical 2002 value: $0.0025/gallon
Make-Up Water Temperature	50 F	

Note: Enter average values for the operating period being modeled

Boiler fuel - Choose from this drop-down list		Natural Gas
Site Fuel Cost per 1000 s.cu.ft	5.00 $	Typical 2002 value: $5.00/(1,000 s cu.ft)

Note: Fuel HHV is 1,000 Btu per s cu.ft (21,032 Btu/lbm)

Steam Distribution	**Input Data**	**Warnings**
High Pressure (HP)	600 psig	
Medium Pressure (MP)	150 psig	
Low Pressure (LP)	20 psig	
HP Steam Use by Processes	50 klb/h	
MP Steam Use by Processes	100 klb/h	
LP Steam Use by Processes	200 klb/h	

Note: Enter process steam use at each pressure level. Excludes turbines, letdowns, leaks, trap losses, deaeration steam and vents

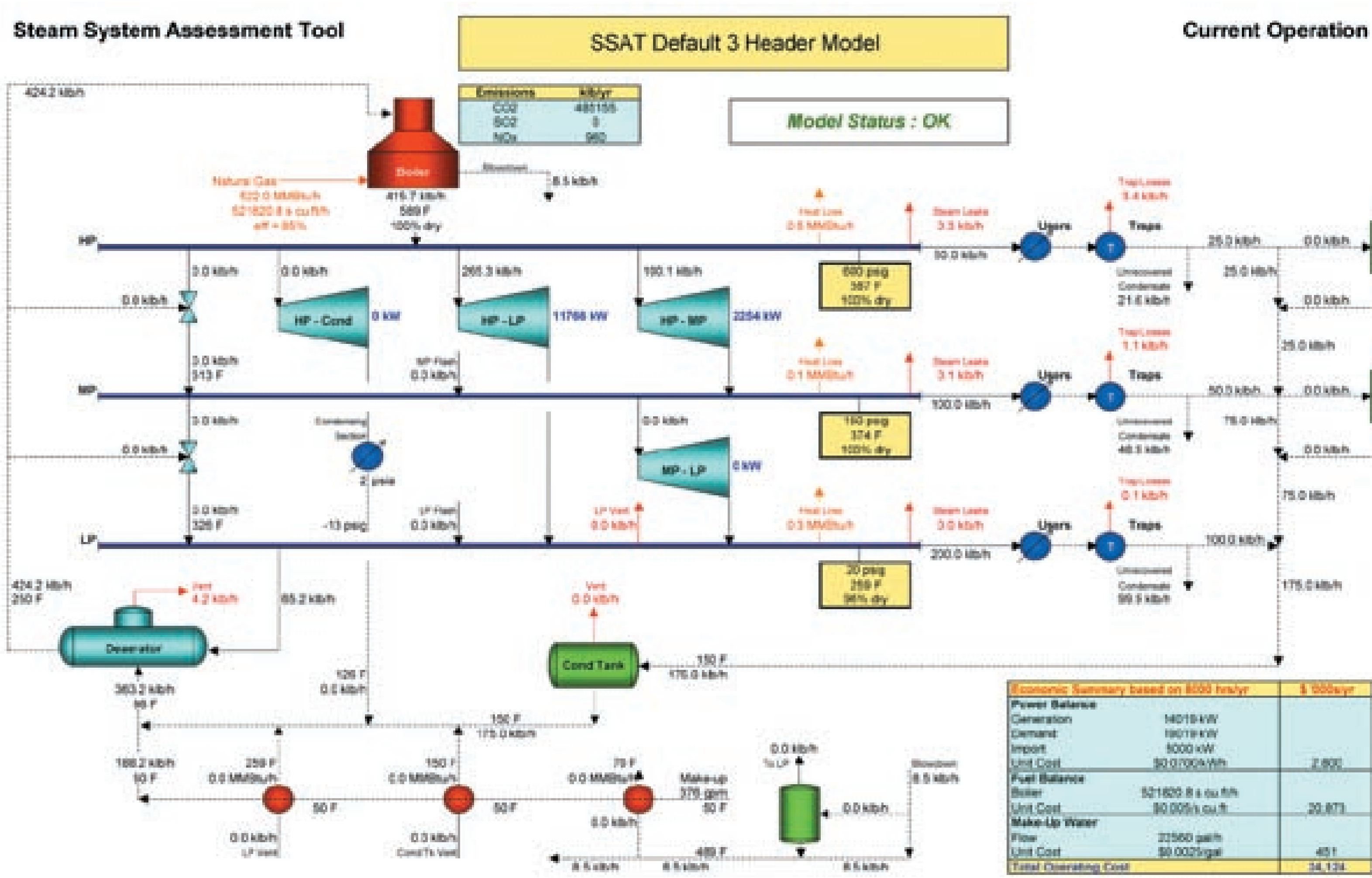
Steam Turbines	
Do you have a steam turbine installed between HP and LP?	Yes
Do you have a steam turbine installed between HP and MP?	Yes
Do you have a steam turbine installed between MP and LP?	No
Do you have an HP to condensing turbine installed?	No

For a **Condensing Turbine**, please define how the turbine operates and then provide supplementary information below:

Mode of operation	Not installed

Option 1 - Fixed power generation	1000 kW	
Option 2 - Fixed steam flow	50 klb/h	

Appendix 2. SSAT Graphical Model Worksheet, 3-Header Template



Appendix 3. SSAT "Projects Inputs Worksheet 3-Header Template (Full Worksheet Not Shown)

Steam System Assessment Tool

3 Header Model

Projects Entry Form

Use this form to specify improvement projects. These projects will then be modeled and compared to the existing operation.

Project 1 - Use an Alternative Fuel
Existing Boiler Fuel : Natural Gas Fuel Cost : $0.005/s cu.ft

Do you wish to specify an alternative fuel?		No
If yes, choose a new fuel from this drop-down list		Number 2 Fuel Oil
Site Fuel Cost	0.67 $/gallon	Typical 2002 value: $0.67/gallon

Note: HHV for alternative fuel is 139,213 Btu per gal (18,275 Btu/lbm)

Project 2 - Change Boiler Efficiency
Existing Efficiency : 85%

Do you wish to specify a new boiler efficiency?		No

Note: An example use of this project option is to model the effect of installing an economizer by increasing the efficiency

If yes, enter new boiler efficiency (%)	90 %	

Note: Typical Best Practice boiler efficiency for Natural Gas is 85%

Project 3 - Change Boiler Blowdown Rate
Existing Blowdown Rate : 2%

Do you wish to specify a new boiler blowdown rate?		No
If yes, enter new rate (% of feedwater flow)	1 %	

Project 4 - Blowdown Flash to LP
Not currently installed

Do you wish to modify the blowdown flash system?	Option 2 - No change

Project 5 - Change Steam Generation Conditions
Existing Conditions : 600 psig, Superheated steam at 589 F

Do you wish to change the HP steam generation conditions?		Option 3 - No change
Option 1 - Enter temperature	600 F	

Note: Saturation temperature at specified HP pressure (600 psig) is 489 F

Option 2 - Enter thermodynamic quality	99.9 % dry	

Appendix 4. SSAT "Results " Worksheet, 3-Header Template (Full Worksheet Not Shown)

Steam System Assessment Tool

3 Header Model

Results Summary

BestPractices
Energy Smart Technology for Today

SSAT Default 3 Header Model

Model Status : OK

Cost Summary ($ '000s/yr)	Current Operation	After Projects	Reduction	
Power Cost	2,800	2,800	0	0.0%
Fuel Cost	20,873	20,873	0	0.0%
Make-Up Water Cost	451	451	0	0.0%
Total Cost (in $ '000s/yr)	**24,124**	**24,124**	**0**	**0.0%**

On-Site Emissions	Current Operation	After Projects	Reduction	
CO2 Emissions	485155 klb/yr	485155 klb/yr	0 klb/yr	0.0%
SOx Emissions	0 klb/yr	0 klb/yr	0 klb/yr	0.0%
NOx Emissions	960 klb/yr	960 klb/yr	0 klb/yr	0.0%

Power Station Emissions	Reduction After Projects	Total Reduction	
CO2 Emissions	0 klb/yr	0 klb/yr	-
SOx Emissions	0 klb/yr	0 klb/yr	-
NOx Emissions	0 klb/yr	0 klb/yr	-

Note - Calculates the impact of the change in site power import on emissions from an external power station. Total reduction values are for site + power station

Utility Balance	Current Operation	After Projects	Reduction	
Power Generation	14019 kW	14019 kW	-	-
Power Import	5000 kW	5000 kW	0 kW	0.0%
Total Site Electrical Demand	19019 kW	19019 kW	-	-
Boiler Duty	522.0 MMBtu/h	522.0 MMBtu/h	0.0 MMBtu/h	0.0%
Fuel Type	Natural Gas	Natural Gas	-	-
Fuel Consumption	521820.8 s cu.ft/h	521820.8 s cu.ft/h	-	-
Boiler Steam Flow	415.7 klb/h	415.7 klb/h	0.0 klb/h	0.0%
Fuel Cost (in $/MMBtu)	5.00	5.00	-	-
Power Cost (as $/MMBtu)	20.51	20.51	-	-
Make-Up Water Flow	22560 gal/h	22560 gal/h	0 gal/h	0.0%

Turbine Performance	Current Operation	After Projects	Marginal Steam Costs	
			(based on current operation)	
HP to LP steam rate	44 kWh/klb	44 kWh/klb	HP ($/klb)	7.03
HP to MP steam rate	23 kWh/klb	23 kWh/klb	MP ($/klb)	5.45
MP to LP steam rate	Not in use	Not in use	LP ($/klb)	3.92
HP to Condensing steam rate	Not in use	Not in use		

List of Selected Projects

Gas Turbine Assessment
Your site is a very good candidate for the installation of a gas turbine + waste heat boiler

Warnings - Any warnings listed below may impact on the validity of the simulation	
Current Operation	After Projects